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Land-use pattern scenario analysis using planner agents

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Abstract. Land-use pattern is one of the key issues in the compilation of urban master plans. In China, government, planners, and residents, all with various requirements and preferences, are the main agents participating in this process. Among them, planners play a role in negotiating with related agents and then establishing land-use patterns. In this paper we propose a planner agent framework to support land-use pattern scenario analysis (LUPSA), based on existing planning support system (PSS) research. Planner agents are divided into three types: nonspatial planner agent (NPA), spatial planner agent (SPA), and chief planner agent (CPA). The NPA is responsible for formulating special plans (such as transport, municipal public facilities, or nature reserve plans) that correspond to available data (such as road network, public facilities, and nature reserve patterns) from LUPSA. The SPA is responsible for establishing land-use patterns. The SPA considers constraints of local development conditions and communicates and coordinates with the NPAs to confirm formulated special plans that can support the implementation of the established land-use pattern. The CPA is responsible for negotiating with the government agent to ensure the reasonability of comprehensive constraints, establishing the final land-use pattern based on an evaluation of established scenarios by several SPAs, then determining it after a public participation process involving local residents. We initially tested this framework in a hypothetical city, then did an experiment in Beijing. Results show that the proposed planner agent framework is suitable for LUPSA.

Keywords: planner agents; planning support system (PSS), land-use pattern, Beijing

1 Introduction

Urban master planning is a key tool of the government for regulating urban growth. Land-use patterns, defined herein as spatial distributions of different land-use types and development densities for parcels or blocks, are key issues in carrying out an urban master plan. In China the government, urban planners, and local residents are main agents participating in analyzing the land-use pattern. According to the Urban and Rural Planning Act of the People's Republic of China, put into effect in 2008, the government organizes the establishment of an urban master plan; planning institutes or agencies are authorized to undertake the specific establishment work; and before approval is granted the plan should be announced and opinions from the public should be collected by means of argumentation and hearing. Specifically, the government has a role in determining the overall goals of social, economic, and environmental development under the constraints of local development conditions; planners play a role in negotiating with related agents and then establishing land-use patterns. Residents provide suggestions and feedback to the relevant agents. All

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these participants have varying requirements and preferences for the land-use pattern. For example, specifically, the government wants to improve social, economic, and environmental development simultaneously, planners emphasize implementation of a specific planning concept, and some residents are concerned with parks or shopping centers being situated near their living space. In reality, demands and inclinations, however, frequently do not meet well with city development regulations. In order to reach a consensus, negotiation and communication are necessary. Planners, rich in knowledge and experience and usually having good communication skills, are the negotiators. With negotiation between planners and the government and between planners and residents, a good balance may be achieved among different stakeholders. Establishing land-use patterns using conventional planning means a lack of effective methods to reflect the planner's role in the process of establishing the land-use pattern and the negotiation process among various agents. This is likely to cause an overstrengthening of a certain agent's effect, and ignorance of, or weak compliance with the requirements and preferences of other agents, thereby reducing the plan's suitability.

The planning support system (PSS), a computer-aided instrument specifically designed to support comprehensive tasks in urban planning, is based mainly on theories and technologies such as geographic information systems (GIS) and planning models and visualizations (Brömmelstroet, 2012; Klosterman, 1997). PSS has been widely discussed and applied in the field of urban planning for decades (Brail, 2008; Couclelis, 2005; Geertman and Stillwell, 2004; Long et al, 2011a; Stillwell, 2002; Vonk and Ligtenberg, 2010). Scenarios are a series of conjectures about what might happen in the future (Cornish, 2004). When it comes to the domain of urban planning, scenarios as a means of representing the future have been in the land-use planner's toolkit for several decades (Xiang and Clarke, 2003). Scenario planning has proven to be a disciplined method for imagining possible futures in which decisions may be played out (Schoemaker, 1995), and is a powerful tool for asking 'what if' questions to explore the consequences of uncertainty (Duinker and Greig, 2007).

There are plenty of studies of LUPSA using PSS. For example, California urban futures (CUF) developed by Landis (1994) can replicate realistic urban growth patterns and the impacts of development policy at various levels of government, and allocate urban growth to sites on the basis of development profitability. What if?, developed by Klosterman (1999), can indicate efficiently the influence of planning management, and has been used widely in other studies such as growth management strategy evaluation and land-use forecasting (Klosterman et al, 2006; McColl and Aggett, 2007). INDEX, developed by Criterion Planners, can evaluate planning influence in multiple aspects, including the environment, energy, transport, and public finance (Allen, 2001). Ligmann-Zielinska and Jankowski (2007) generated future development scenarios for a small community using comprehensive growth plans and an agent-based model (ABM) method. iCity (Stevens et al, 2007), which is based on vector cellular automata (CA), was a novel model for urban growth simulation to aid spatial decision making for urban planners. Ligmann-Zielinska et al (2008) presented a spatial optimization model, which encourages efficient utilization of urban space through infill development, compatibility of adjacent land uses, and defensible redevelopment, and used it to generate land-use alternatives for further consideration in spatial decision making. Shen et al (2009) took into account the effects of urban planning at the level of parcels or blocks in urban space, and visualized land-use patterns using CA. Long et al (2011b) developed an urban containment PSS in Beijing for automatically compiling the urban containment plan, which represented constraints on the land-use pattern. Cao et al (2012) developed a land-use optimization model to support the generation of near-optimal planning scenarios considering multiobjectives with different preferences. As a tool for spatial plan design, Landscape Generator, developed by Slager and de Vries (2013), can generate spatial plans with a high level of detail and realism using a simple set of rules. Porta et al (2013) used genetic algorithms to formulate land-use plans based on a cadastral parcel map. While addressing well the issues of LUPSA, the above studies do not deal with the LUPSA process from the planner's perspective, which is actually closer to the real situation. In general, most applications can only complete a portion of the LUPSA tasks, such as urban land boundary formulation, planning evaluation, and constraints acquisition. The importance of planners and the influence of their behavioral characteristics seem to be ignored, even though the research may be aimed at supporting the work of the planner and may have considered many planning factors. In these studies, planners may be the evaluators or users of the simulated scenarios, but not the emphasized actor (or factor) who (or which) influences land-use change during the simulation process.

There are several studies related to highlighting planners in LUPSA by means of planner agents (PAs). For example, Ligtenberg et al (2001) defined the planning actor as the person who has the authority to change the spatial organization; the planning actor makes decisions based on the opinions of the other actors and his or her personal ideas. Ligtenberg et al (2009) extended their existing 2001 research with the principle of sharing knowledge among participating actors, who have desires and preferences regarding the future development of their environment, and a facilitator agent, who is designed to minimize the conflicts among the actors. Saarloos et al (2005) defined agents as land-use experts who initiate the development of plan proposals and communicate with each other over time, for drawing up proposals incrementally. Agent iCity, developed by Jjumba and Dragicevic (2012), is an upgraded version of iCity, and can simulate the land-use pattern by incorporating interactions of various stakeholders; a planning agent is designed to simulate the activities of the city planners and the primary goal is to select and demarcate the parcels upon which future growth can happen. ABMland (Schwarz et al, 2012) is a tool for developing agent-based models for urban land-use change, and includes six major agent types: residents, planners, infrastructure providers, businesses, developers, and lobbyists. Pooyandeh and Marceau (2013) developed an ABM in an interactive visualization environment provided through a web interface to facilitate the learning and negotiation of the stakeholders for land development. The above researches emphasize that the planner or planning stakeholder should be considered as an agent affecting the land-use change, and provide several methods to support the negotiation among participating stakeholders. However, consideration of the planner's role is not enough if the influence of their requirements and preferences is ignored or not detailed. In addition, the relationship between the planners responsible for the land-use pattern and those responsible for other types of plans (eg, for transport and public facilities) was not considered. Furthermore, many researches are not carried out with empirical studies in real cities.

In this paper, we propose the PA framework for supporting LUPSA, on the basis of existing PSS research. In this framework, three types of agents are included: government, planner, and resident agents. PAs are divided into three types: spatial PA (SPA), nonspatial PA (NPA), and chief PA (CPA). We identify planning rules (PRs) for reflecting planner requirements and preferences through existing plan drawings and questionnaire surveys conducted at professional institutions in China. The land-use pattern can be established by the SPA combined with identified PRs, comprehensive constraints made by the government agent (GA), and special plans formulated by the NPAs. Compared with existing researches, the PA framework emphasizes not only the uniqueness of planners and the influence of their opinions, but also the importance of other agents; it considers the negotiation between planners and other agents, and that between different PAs. The framework is proposed and described in detail in section 2. In section 3 it is tested, initially in a hypothetical city and followed by an experiment in Beijing (see section 4), to demonstrate the applicability of this framework. Finally, in section 5, we conclude and propose the benefits and future research paths.

2 Framework and methods

2.1 Basic concepts

2.1.1 *Planner Agents*

According to the content of the work performed by urban planners in LUPSA, and based on the planning practice in China (Gu, 2011), PAs are divided into NPA, SPA, and CPA here. The NPA is responsible for formulating special plans, such as for transport, municipal public facilities, and nature reserves, which correspond to data concerning the road network, public facilities, and nature reserve zones. Special plans formulated by NPAs are parts of an urban master plan. The SPA is responsible for establishing land-use patterns. The SPA considers constraints of local development conditions, and communicates and coordinates with the NPAs to confirm formulated special plans that can support implementation of the established land-use pattern. The CPA is responsible for negotiating with the GA, ensuring the rationality of comprehensive constraints, establishing the final land-use pattern based on an evaluation of established scenarios by several SPAs, then determining the final land-use pattern after the public participation process involving a resident agent (RA). When the CPA negotiates with the GA and RA, it is on behalf of the planning institution, not a planning bureau. Decision makers in the planning bureau, with extensive knowledge on behavior and preference, are not accounted for in this paper, which focuses on planners.

2.1.2 *Planning rules*

There are some relevant explanations about the requirements and preferences of participant agents (Ligtenberg et al, 2001; 2009; Saarloos et al, 2005). In this paper the demands and inclinations of the GA and RA are not discussed specifically. The concept of PRs is given here, and then used to reflect the requirements and preferences of PAs.

PRs are criteria or guidelines of planners' thinking and actions during the LUPSA process. The main content of PRs consists of the planners' considered planning impact factors (PIFs) and their weights. There are many PIFs for land-use patterns, such as roads, rivers, parks, and traffic noise. Different planners, with varying demands and inclinations, will consider different sets of PIFs, for which weights are usually different. For example, planner A may believe parks and rivers are the most critical PIFs for a residential parcel pattern, whereas planner B only considers the park as a PIF, but just a normal one. In this case, the river is not a PIF for B, and the park weight of planner B is less than that of planner A. The planner's PRs reflect his or her requirements and preferences. For example, whether to consider the river and the determination of its weight for a residential parcel pattern reflects the demands and inclinations of a riverfront development strategy. In the following, planner requirements and preferences are regarded as the same as his or her PRs in the following sections of this paper.

According to LUPSA tasks, PRs mainly consist of parcel partitioning, land-use type, and development intensity determinations. Considering this paper as the first exploration step for PAs, we focus on how to determine land-use type at present, with primary consideration of planner requirements and preferences regarding, for example, parcel size, street scale, riverfront development, transit-oriented development, compact city, and mixed use.

2.2 The framework of LUPSA using planner agents

The flow of LUPSA using PAs is as follows:

(1) The GA determines comprehensive constraints and negotiates them with the CPA.

(2) PRs are identified through existing plan drawings, questionnaire surveys, or other means.

(3) NPAs carry out various special plans (formulated special plans are treated as exogenous variables).

(4) The SPA establishes the land-use pattern, combining the identified PRs, comprehensive constraints, and formulated special plans.

(5) The SPA negotiates with the NPAs to confirm whether special plans can support implementation of the established land-use pattern. If not, the SPA revises the established land-use pattern or the NPAs revise any special plans, until both sides meet with each other (not considered in this stage).
(6) The CPA establishes the final land-use pattern based on land-use patterns established by various SPAs.
(7) The CPA determines the final land-use pattern, after negotiating with the RA (not considered in this stage).
See figure 1.

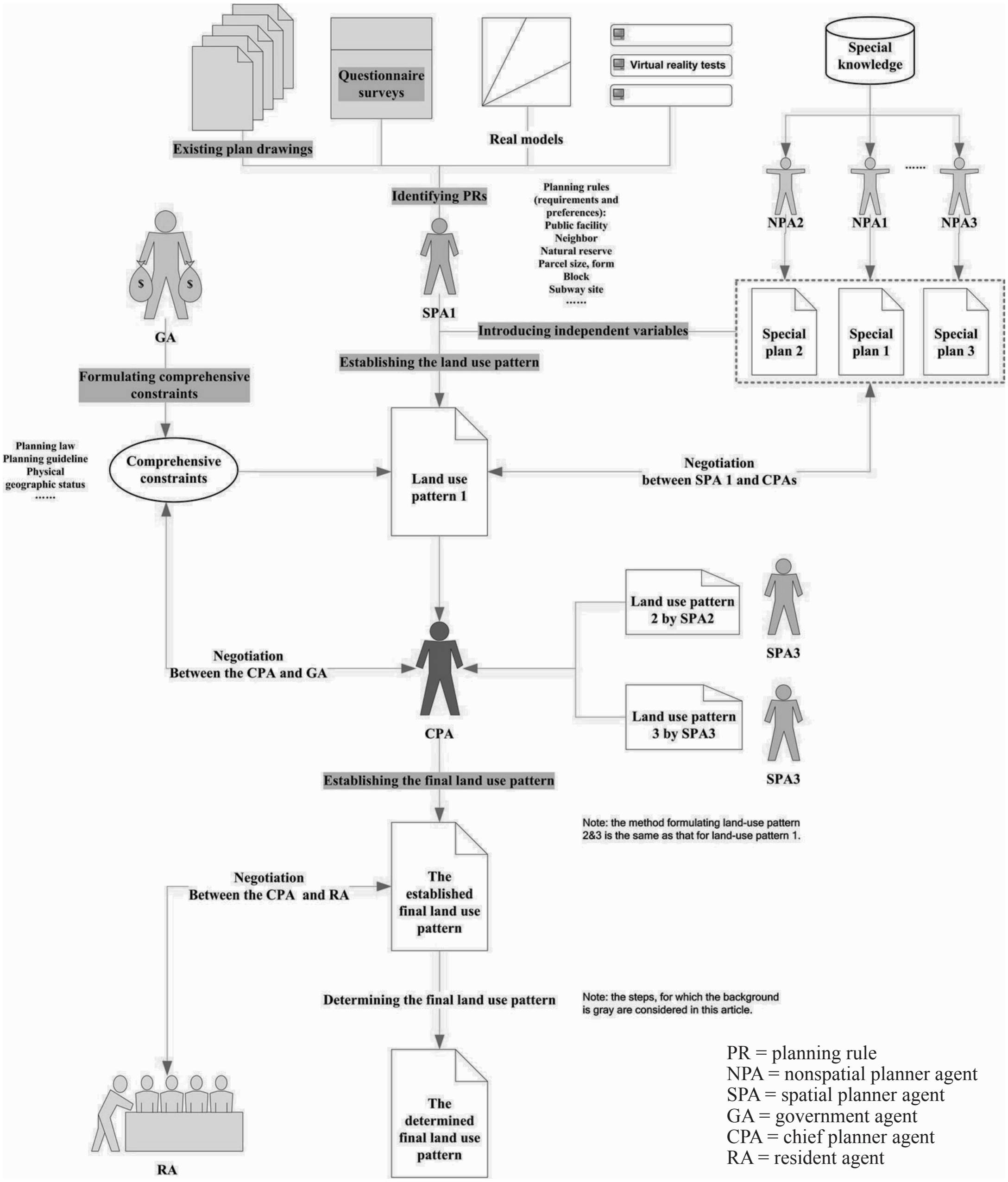

Figure 1. [In color online.] Flow diagram of land-use pattern scenario analysis using planner agents.

2.3 Methods

2.3.1 *Obtaining comprehensive constraints*

The GA considers spatial constraints in the form of relevant laws, regulations, planning standards, and physical geographic status when determining overall goals of social, economic, and environmental development. These are called comprehensive constraints, and reflect relevant political influence to the LUPSA. Comprehensive constraints can be divided into several types, including land-use type, land-use quota, building height, underground construction, and city activity constraints, and the first two types are considered in this paper. Land-use-type constraints, caused by some policies, such as urban growth boundaries and agricultural land preservation, mean that it may be forbidden to develop a parcel as a particular or several land-use type(s) (Long et al, 2006; 2011b). Land-use quota constraints mean that the total area of parcels of a certain land-use type should be as similar as possible, but no more than the planned quota for an established land-use pattern. This can be determined according to the specific objectives of city development as well as the urban planning standard; for example, the area of residential parcels should be no more than a stated amount according to the urban master plan.

Before determining comprehensive constraints, the GA negotiates with the CPA, who evaluates the reasonability of the determination using knowledge and experience. If it is irrational or hard to realize for the city, the constraints should be revised. The negotiation process between the GA and CPA is not considered in this paper.

2.3.2 *Identifying planning rules*

We identified PRs (PIFs and their weights) through existing plan drawings and questionnaire surveys, conducted at professional institutions in China. The PR identification may also be implemented using other methods such as real models or virtual reality tests. For example, Hatna and Benenson (2007) identified the rules of city construction using building blocks, Crompton (2012) calculated information content using LEGO® sets as a language, and Minnery and Searle (2013) analyzed the impact of using SimCity™4 to build simulated cities.

PRs can be identified through existing plan drawings using multinomial logistic regression (MLR), a comparatively mature method, that is used widely in urban models (Bendor et al, 2013; Waddell, 2002). In this process the parcel is treated as a research unit, the parcel's planned land-use type as a dependent variable, and the PIF as an independent variable to identify the weight of every PIF for every planned land-use type. The detailed calculation method is as follows:

$$T = \{t_k \mid k = 1, 2, 3, \ldots, K\} , \tag{1}$$

$$F = \{f_i \mid i = 1, 2, 3, \ldots, I\} , \tag{2}$$

$$P = \{p_n \mid n = 1, 2, 3, \ldots, N\} , \tag{3}$$

$$W = \{w_{ik} \mid i \in [1, I], k \in [1, K]\} , \tag{4}$$

$$P_{nk} = \frac{\exp\left(r_k + \sum_{i=1}^{I} w_{ik} f_i\right)}{1 + \sum_{k=1}^{K-1} \exp\left(r_k + \sum_{i=1}^{I} w_{ik} f_i'\right)} , \tag{5}$$

where t_k is the planned land-use type, K is its number, f_i is the PIF, I is its number, p_n is the parcel, N is its total amount, w_{ik} is the weight of f_i for t_k, P_{nk} is the probability of p_n for t_k , and r_k is the corresponding constant term.

For existing plan drawings, variables T (residential R, commercial C, industrial M, and others O), F (corresponds to special plans), and P and P_{nk} (0 or 1) are known, so W can be calibrated via regression, and W and F together constitute PRs.

PRs can also be identified through questionnaire surveys. PIFs can be confirmed by planners prior to surveys, and PIF weights are reflected in scoring by the respondents. For example, for the R-type development, if respondent A feels strongly about whether a parcel is close to a main road, the weight of the PIF main road would be 9; if this PIF is not important to the respondent, the score would be 0. Accumulating the information from a number of such questionnaires, the identified PRs become reasonable.

2.3.3 *Establishing the land-use pattern*

The NPAs formulate any special plans; however, this formulation is not considered here. Existing special plans are used to identify PRs, and formulated special plans are used to support the establishment of the land-use pattern.

According to identified PRs and formulated special plans, variables T, F, P and W are known, so P_{nk} can be estimated via regression. Then, combined with comprehensive constraints, the land-use pattern can be established. Using T (which includes R, C, and M) as an example, the detailed flow is as follows.

(1) Calculate P_R, P_C, and P_M of parcel n, combined with formulated special plans (PIFs) and their weights, and land-use-type constraints (if parcel n is constrained by land-use k, P_k will be 0).

(2) Compare the values of P_R, P_C, and P_M of parcel n, to determine n's suitable land-use type CompType, for which the value is R, C, or M.

(3) According to land-use quota constraints, compare the value of P_R (then P_C and P_M) of all parcels, to determine which parcels are suitable to be distributed as R. The total area of suitable R parcels should be close to but no more than a certain planned quota. If parcel n is suitable to be distributed as R, then the comparative value of RList is YES; otherwise, it is NO. The value of RList reflects whether the parcel would be included in the list of parcels which should be distributed as R according to the land-use quota constraint.

(4) For parcel n, if there is one of the variables RList, CList, or MList for which a value of YES exists (all other values are NO), for example, RList, then parcel n's final distributed land-use type is R.

(5) For parcel n, if there are at least two of the variables RList, CList, or MList for which values are YES, there is a contradiction in the land-use pattern. Then, the land-use type with the greatest P value would be determined as the final land-use type.

(6) Calculate the total areas of land-use types R, C, and M. If the total area of a certain land-use type—for example, R—is less than the land-use quota constraint, we should assign R to the remaining parcels, until the requirement quota is met.

(7) After step (6), if the distributed area of a certain land-use type is still less than the land-use quota constraint, then determine the final land-use type of the remaining parcels randomly, until the quota is met.

2.3.4 *Negotiation between the spatial and nonspatial planner agents*

During and after establishing the land-use pattern, the SPA negotiates with the NPAs to confirm whether special plans could support implementation of the established scenario. Whether the land-use pattern can be implemented in urban practice can be evaluated according to whether the required spatial policies reflecting planning controls on spatial constraints exist.

Here, special plans are regarded as spatial constraints for the implementation of the established land-use pattern, and a policy parameter is the implementation intensity of planning controls on the corresponding spatial constraint (Long et al, 2012). If a policy parameter set can be identified, there exists a suitable implementation intensity for each special plan. In this case the land-use pattern could be achieved by formulated special plans. Otherwise, the SPA revises the established land-use pattern or the NPAs revises any special plans, until both agree. The negotiation process can be implemented by using our existing research (Long et al, 2010; 2012).

2.3.5 *Establishing the final land-use pattern*

The CPA establishes the final land-use pattern based on an evaluation of all established land-use patterns by various SPAs. Several evaluation methods can be adopted. For example, calculating landscape metrics to evaluate spatial characteristics (Aguilera et al, 2011; Botequilha-Leitão and Ahern, 2002), using FRAGSTATS (McGarigal and Marks, 1994), and potential transport energy consumption using the urban form–transportation energy consumption–environment–MAS model (FEE-MAS) developed by Long et al (2013).

In this paper the CPA evaluates the probability of P_{nk} via summing the frequencies of land-use type *k* (R, C, M) for parcel *n* in all established scenarios, then establishes the final pattern using the flow used by the SPA, as described in subsection 2.3.3. For example, among 10 established scenarios, there are 2, 3, and 5 SPAs allocating parcel *n* as R, C, and M types, respectively, so P_{R}, P_{C}, and P_{M} of parcel *n* are 0.2, 0.3, and 0.5, respectively. The method considers the requirements and preferences of all participating SPAs equally; it can also be improved by considering different weights for scenarios established by different planners.

2.3.6 *Determining the final land-use pattern*

The CPA should negotiate with the RA to ensure the final land-use pattern could reflect the requirements and preferences of the public. The negotiation process could be conducted via planning meetings, participating workshops, questionnaire surveys, or web-based approaches (Bugs et al, 2010). After the negotiation between the CPA and RA, the CPA may revise the pattern, or require other related agents (eg, the SPA) to revise it. Finally, the CPA determines the final land-use pattern, which is an "ideal" scenario and can meet the requirements and preferences of all agents. Because the process of the RA's participation has been studied extensively, this process is not included in the present paper.

3 Virtual space test

To verify the PA framework, we test it in a virtual space, the details of which are as follows.

(1) There are 10 × 10 parcels in the virtual space, and the length of each parcel is 1. The transportation network (figure 2) is a homogeneous grid shape (corresponding to the parcel boundary).

(2) There are three land-use types—R, C, and O. The numbers of existing R and C parcels are 5 and 6, respectively; 25 R parcels and 15 C parcels are to be developed, which corresponds to the land-use quota constraints in the LUPSA process.

(3) Land-use type constraints consist of R (land-use type is constrained to be R) and similarly C, R and C, and no constraint. Existing R and C parcels remain unchanged.

(4) The school plan, road plan, and central business district (CBD) location, which correspond to PIFs, are special plans formulated by NPAs.

(5) Existing PRs of three SPAs are known (table 1).

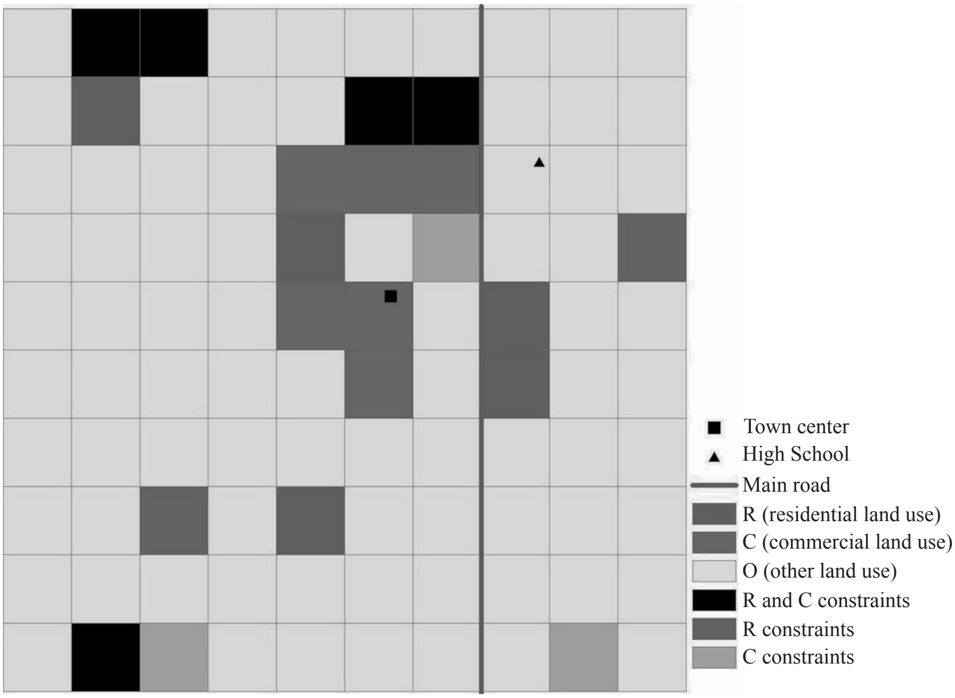

Figure 2. [In color online.] The virtual space.

Table 1. Existing planning rules (PRs).

Planning impact factor	Weight								
	PR 1			PR 2			PR 3		
	R	C	O	R	C	O	R	C	O
High school	0.5	0.3	0.2	0.5	0.4	0.1	0.4	0.4	0.2
Town center	0.3	0.4	0.3	0.3	0.5	0.2	0.6	0.3	0.1
Main road	0.5	0.4	0.1	0.4	0.5	0.1	0.5	0.4	0.1

Note. R = residential land use, C = commercial land use, O = other land uses.

The PA model was developed using Python and Geoprocessing, to support LUPSA. Here, only accessibility is considered. The shortest Euclidean distance dist from the parcel to the PIF can be calculated using the Distance/Straight Line tool in ArcGIS. The impact force f, determined by dist, is calculated according to Equation (7), and we set $\beta = 0.001$ empirically.

$$f = \exp(-\beta\,\mathrm{dist}) \,. \tag{7}$$

Combined with comprehensive constraints, existing PRs, and formulated special plans, the SPA establishes the land-use pattern. The results are shown in figures 3(a), 3(b), and 3(c). In scenario 1 [figure 3(a)], newly developed R parcels are mainly distributed in the east, close to the high school and main road; newly developed C parcels are mainly distributed in the south, close to the CBD or main road. Overall, patterns of scenarios 1 and 2 are similar; newly developed R parcels are distributed in the northeast, and increased C parcels in the south. The pattern of scenario 3 is different from those of scenarios 2 and 3, and newly developed R and C parcels are distributed in the southeast and northeast.

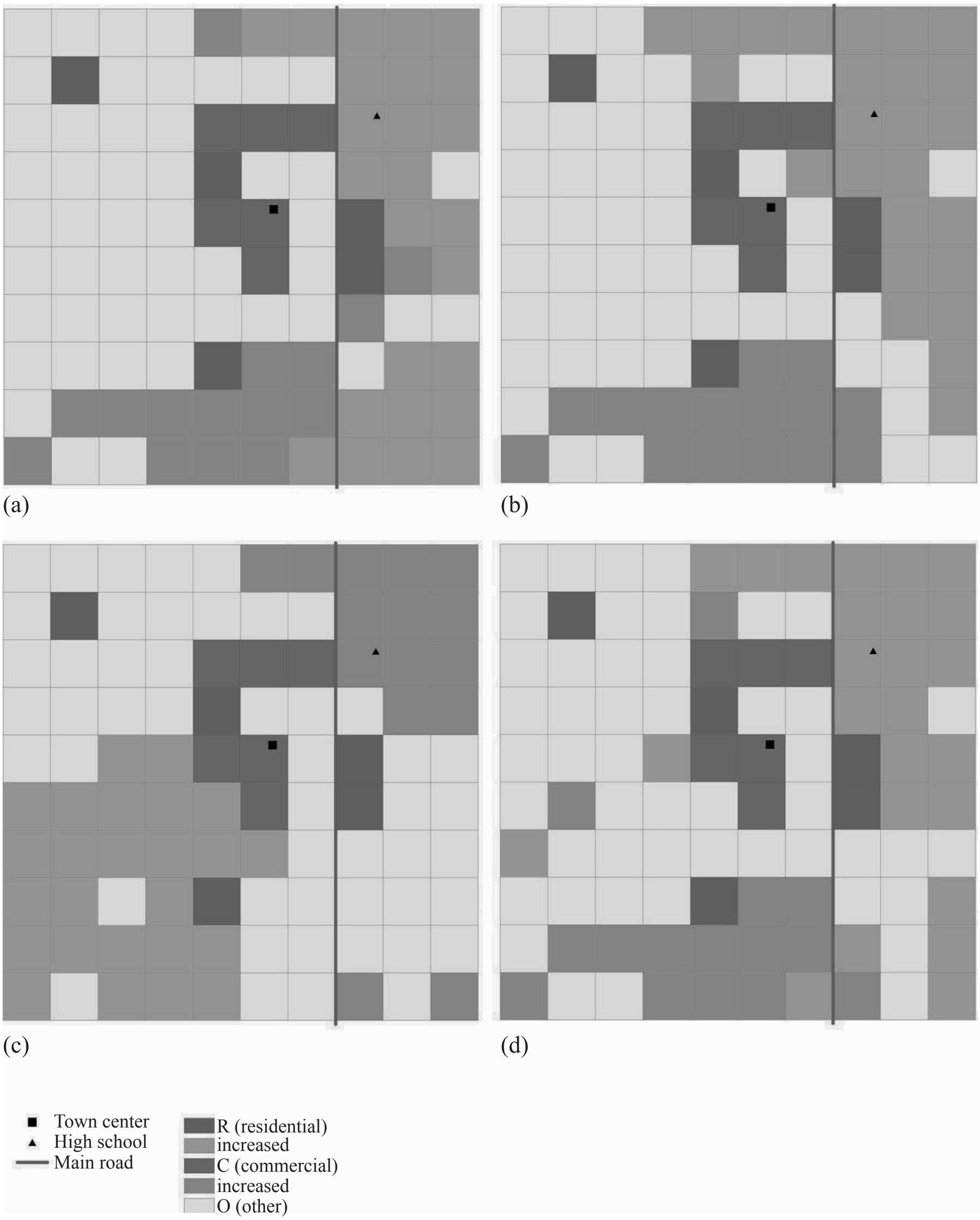

Figure 3. [In color online.] Established land-use patterns; (a), (b), (c), and (d), respectively, represent scenarios 1, 2, and 3 established by the spatial planner agents using planning rules 1, 2, 3, and the final scenario established by the chief planner agent

The CPA evaluates land-use patterns by equal consideration of the requirements and preferences of three SPAs. The probabilities of five parcels, located on the upper first row with an order from left to right, are shown in table 2 as examples. For instance, parcel 4 was distributed as R type with a probability of 0.33, and as O type with a probability of 0.67. From the evaluation, the CPA establishes the final land-use pattern, shown in figure 3(d). In general, the final scenario is similar to scenarios 1 and 2, but the distributions of newly developed R and C parcels are more dispersed. The result reflects well the opinions of SPA1

Table 2. Parcel probabilities for land-use-type allocation.

Parcel number	Probabilities		
	residential	commercial	others
1	0.00	0.00	1.00
2	0.00	0.00	1.00
3	0.00	0.00	1.00
4	0.33	0.00	0.67
5	0.33	0.33	0.33

and SPA2, and partly that of SPA3. The process of RA's participation and final determination is not considered in the current study.

The results of the virtual space test above indicate that the PA framework is feasible for supporting LUPSA.

4 The Beijing experiment

4.1 Study area

The Beijing Metropolitan Area [BMA; figure 4(a)] has an area of 16410 km^2. It has experienced rapid urbanization in terms of gross domestic profit and population growth since the Reform and Opening Policy of 1978, established by the Chinese central government. There are sixteen districts under BMA jurisdiction, and four main districts under the jurisdiction of the Beijing Central Area (BCA). In the Beijing experiment, four land-use types, namely R, C, M, and O, were allocated during the establishing of land-use patterns. In 2010 the BCA urban area was 987.5 km^2, and areas of R, C, and M parcels were 194.6 km^2, 129.2 km^2, and 64.3 km^2, respectively.

4.2 Data

4.2.1 *The BCA detailed plan for identifying planning rules*

The BCA detailed plan for PR identification is shown in figure 4(b). Region A [figure 4(b)] in the BCA, with an area 107.7 km^2 and 336 parcels, was chosen as an experimental area for LUPSA. We suppose the land-use type of all parcels in region A is O initially in the experiment. To identify PRs, planned parcel samples were selected from the BCA detailed plan. There are eighteen regions [region A and regions 2–18, shown in figure 4(b)] located in the outmost part of the BCA. When establishing the BCA detailed plan, each region had a planner responsible for its compilation. We identified each planner's PRs using the parcels he or she was responsible for in a region. Seventeen sets of planned parcels (excluding that of region A), located in the outmost part of the BCA, were extracted for identifying the seventeen planners' PRs, and thereby seventeen different land-use pattern scenarios can be established for a region, say region A. In addition, the set of planned parcels distributed over the entire BCA was also used to identify the 18th set of PRs, which can reflect comprehensively the requirements and preferences of many participating planners. It should also be mentioned that the BCA detailed plan has been formally proved by the municipal government of Beijing, and residents also participated in a form of formal public participation in the process. Therefore, the PRs identified here, revealing planners' preferences, can also reflect the influence of the GA and RA to some extent, rather than solely that of the PAs.

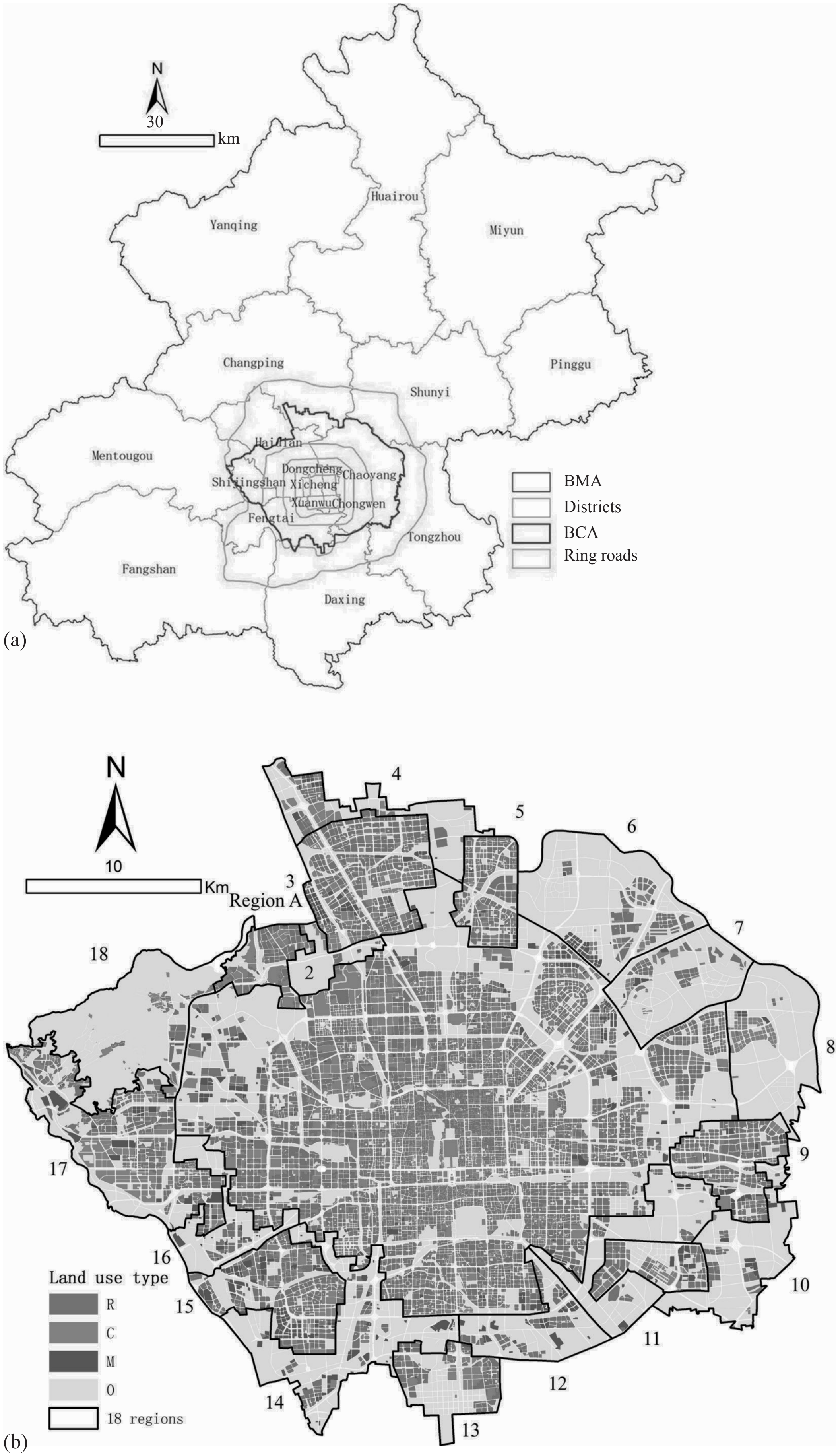

Figure 4. [In color online.] (a) The Beijing Metropolitan Area (BMA) and (b) the Beijing Central Area (BCA) detailed plan with eighteen regions. R = residential, C = commercial, M = industrial, O = other.

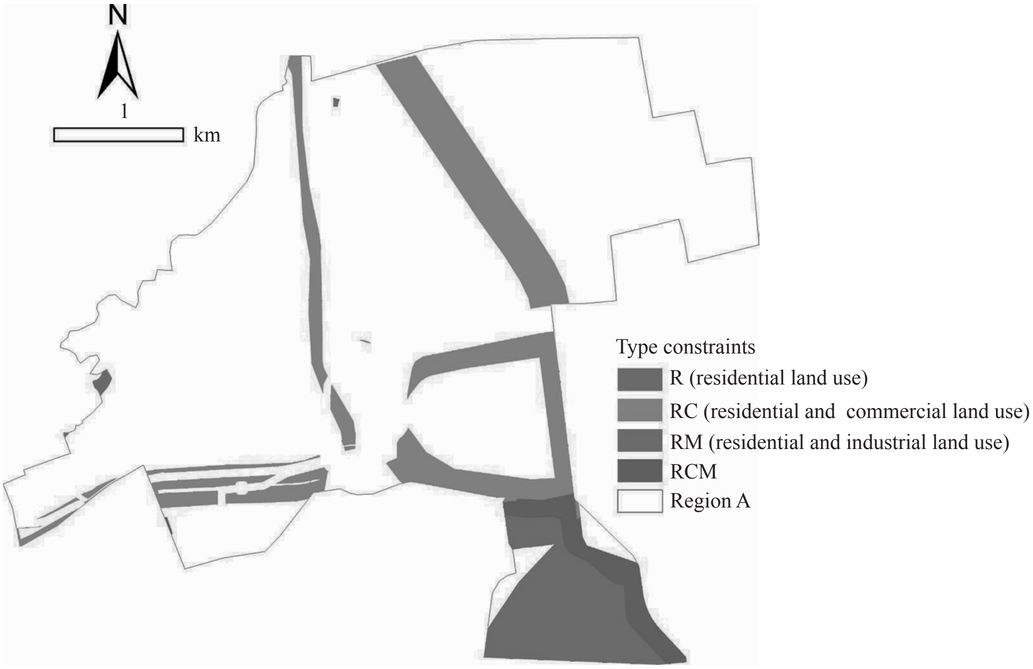

Figure 5. [In color online.] Land-use-type constraints of region A.

4.2.2 *Comprehensive constraints*

The GA determines land-use-type constraints according to the Beijing Urban Containment Plan (Long et al, 2011b). Forbidden land-use type(s) for each parcel in region A was (were) determined and illustrated in figure 5. Land-use quota constraints are determined accordingly for region A, such that areas of R, C, and M parcels are no greater than 43.8 km^2, 44.4 km^2, and 0.5 km^2, respectively.

4.2.3 *Special plans representing the NPAs*

We extracted special plans as PIFs from the Beijing spatial database as shown in figure 6, and they can be classified into three types: transport facilities, public facilities, and location factors.

4.3 Identifying PRs

We first identified PRs using MLR with all parcels in the entire BCA as samples. In the BCA there were 29 799 parcels included in the identification process. Among these, there were 9594 R parcels (32.2% of the total number), 7516 C parcels (25.2%), and 753 M parcels (2.5%). Table 3 shows the identified parameters, namely the PIF weights. If the parameter is positive and closer to a particular factor, the parcel is more likely to be distributed as this land use type. If the parameter is negative and closer to a certain factor, the parcel is less likely to be distributed as this land-use type. The −2 log likelihood decreases from 69 795.7 (intercept only) to 62 575.2 (final), and the significance of the likelihood ratio test is 0.000, which indicates that the regression model is significant.

Identification of PRs for each planner in each region of the BCA is the same as before, so the corresponding results and processes are omitted.

When PRs are identified by questionnaire surveys, we divide PIFs into 5 categories—basic topography, accessibility, parcel intrinsic property, socioeconomic characteristics, and environment—and 28 secondary categories. In the questionnaire surveys the respondent assigns a score of 0 if he or she never considers the influence of a certain PIF, and a score of 9, if the PIF is considered fully. Finally, a total of 20 surveys were completed, of which half were by planners at the Beijing Institute of City Planning and the rest were by graduate

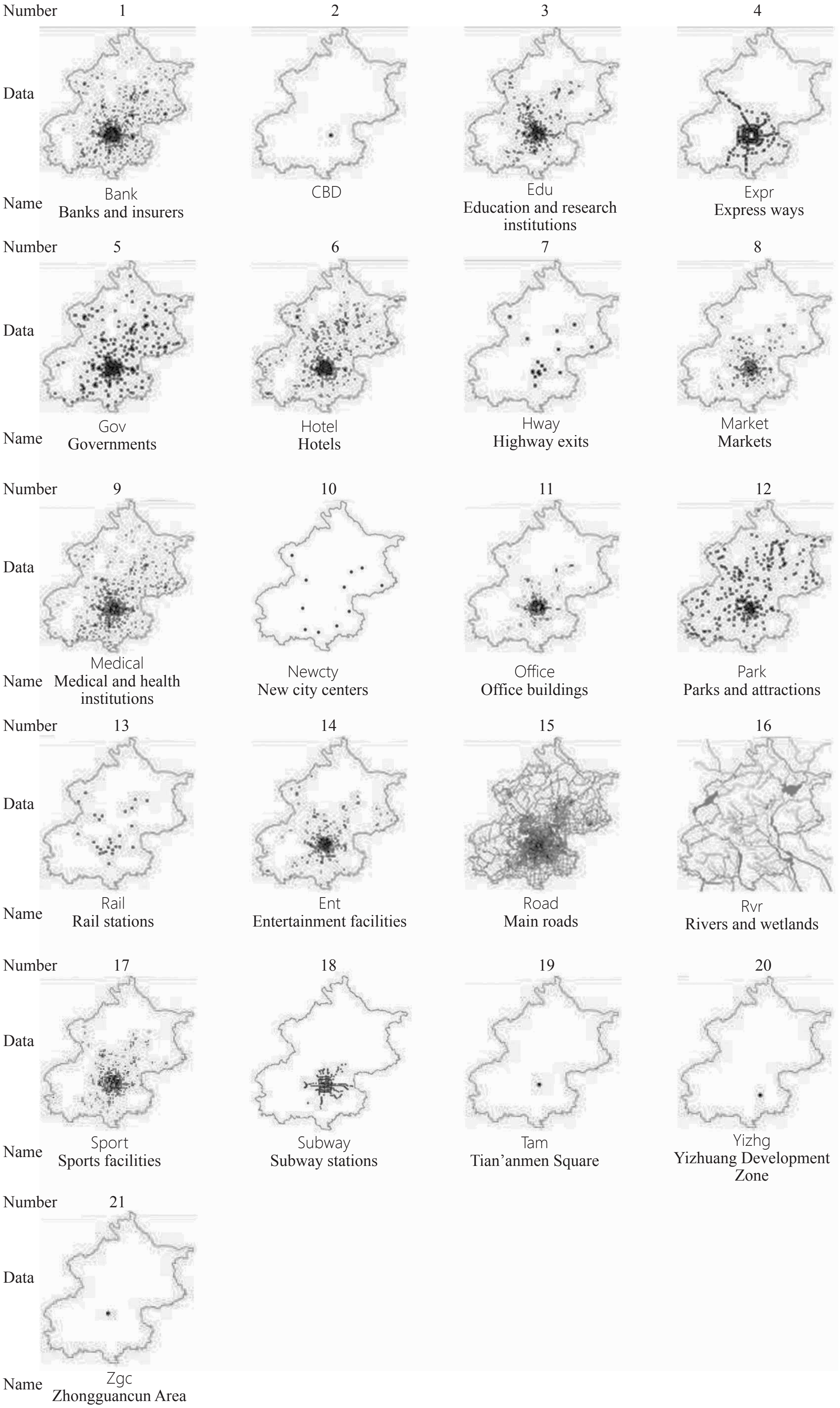

Figure 6. Special plans (also planning impact factors) for the whole Beijing Metropolitan Area.

Table 3. Results of the multinomial logistic regression.

Planning impact factors	Weight[a]		
	R (residential)	C (commercial)	M (industrial)
Intercept	−0.70203***	−2.24992***	−1.78990***
Bank	1.69092***	1.98993***	1.48453***
CBD	−3.13736***	−0.73107***	−7.74911***
Edu	0.59667***	0.83476***	0.57046***
Ent	0.54465***	0.53033***	0.09401
Expr	−0.77072***	−0.81033***	0.21059
Gov	−0.22590***	0.11004	0.78724***
Hotel	0.27165***	0.63531***	−1.50131***
Hway	−0.08708	−0.28315**	−0.95491*
Market	0.59824***	0.10866	−1.50529***
Medical	1.01238***	0.71570***	−0.37010
Newcty	−8.33651**	−0.01048	−1.21120
Office	0.31318***	0.52759***	1.24840***
Park	0.06680	0.14353*	−0.52322**
Rail	−0.29179**	−0.14296	0.79214***
Road	−2.09906***	−1.19993***	−1.10308**
Rvr	−0.26074***	−0.71772***	−1.32691***
Sport	0.19670**	0.20072**	0.34227
Subway	0.36312***	0.57882***	−0.41520**
Tam	0.52299	1.24361***	−39.32950***
Yizhg	−91.77109***	−101.64079***	33.57548**
Zgc	−1.49658***	0.16891	−23.24940***

[a] The reference category is O (other land-use types).
Significance levels: ***$p = 0.01$; **$p = 0.05$; *$p = 0.10$.

students in Urban and Regional Planning at Peking University. The assigned scores are standardized using equation (8), where w_i is the score assigned by 20 respondents and W_i is the standardized score with a range of 0–1.

$$W_i = \frac{w_i}{w_{\mathrm{R}} + w_{\mathrm{C}} + w_{\mathrm{M}}}, \qquad i = \mathrm{R, C, or\ M} . \tag{8}$$

Table 4 shows the PIFs and the standardized weights determined by these individuals, who have either professional or educational backgrounds in urban planning. According to the planner-stated weights, for the R pattern, the most influential PIF is educational and research institutions, and the least influential is development zones. For the C pattern the most influential PIF is the CBD, and the least influential are educational and research institutions and medical and health institutions. The most influential PIFs for the M pattern are development zones and highway exits, and the least influential are subway stations and the CBD.

There are 21 and 17 PIFs in the accessibility category when identified using existing plan drawings and questionnaire surveys, respectively. Among them, 11 PIFs, shown in table 4 using a format with brackets [eg, Rail stations (Rail)], have the same meanings in both methods. Comparing the weights of these 11 PIFs can reveal the differences between the PRs identified by these two methods, like the difference between actual (revealed) and stated preferences, or that between different data sources. The weights identified by existing plan drawings not only reflect the influence level, but also disclose the positive

Table 4. Questionnaire results for planning impact factors (PIFs).

Category	PIF	Weight		
		residential	commercial	industrial
Basic topography	Elevation	0.32	0.31	0.37
	Slope	0.30	0.32	0.39
Accessibilities				
Transport facilities	Airports	0.26	0.31	0.43
	Rail stations (Rail)	0.26	0.37	0.37
	Highway exits (Hway)	0.23	0.25	0.51
	Main roads	0.30	0.34	0.36
	Subway stations (Subway)	0.43	0.43	0.13
	Bus stops	0.42	0.40	0.19
Public facilities	Government departments (Gov)	0.39	0.35	0.26
	Entertainment facilities (Ent)	0.49	0.35	0.16
	Amenities such as supermarkets	0.50	0.32	0.19
	Medical and health institutions (Medical)	0.57	0.21	0.23
	Educational and research institutions (Edu)	0.58	0.21	0.21
	Banks and insurers (Bank)	0.36	0.42	0.22
	Parks and attractions (Park)	0.55	0.29	0.16
Location	CBD (CBD)	0.33	0.52	0.15
	Town centers	0.40	0.47	0.13
	Development zones	0.20	0.29	0.51
	Rivers and wetlands (Rvr)	0.43	0.25	0.32
Parcel properties	Current land use type	0.36	0.31	0.33
	Parcel area	0.29	0.30	0.41
	Land price	0.33	0.32	0.35
Socioeconomic characteristics	Population density	0.36	0.41	0.23
	Employment rate	0.30	0.37	0.32
Environment	Air quality	0.46	0.34	0.21
	Traffic noise	0.56	0.28	0.17
	Vegetation coverage	0.49	0.28	0.23
	NIMBY[a] facilities	0.46	0.36	0.18

[a] Not in my backyard.

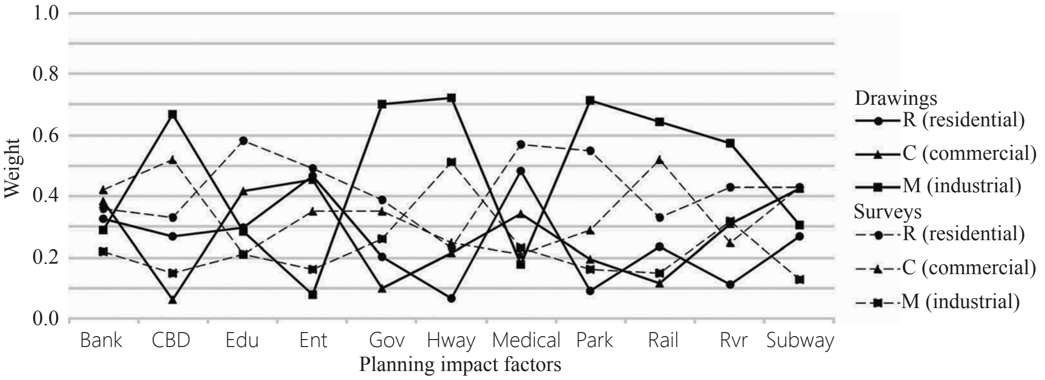

Figure 7. Comparison between the weights identified by existing plan drawings and questionnaire surveys.

or negative influence. Therefore, for the comparison of their importance absolute weights were considered; thus, the positive or negative sign was ignored, and then values were standardized using equation (8).

The results shown in figure 7 indicate that the differences between weights identified by existing plan drawings are usually greater than those identified by surveys. For example, the respective weights of Hway to R, C, and M are 0.07, 0.21, and 0.72 for the drawings, respectively, while for survey they are 0.23, 0.25, and 0.51, respectively. This is partly because the weight identification through plan drawings is much more affected by original data, whereas in the survey respondents could consider the situation more comprehensively. The weights for R from drawings are less than those from surveys, and the weights for M from the former are usually greater than those from the latter. This shows that these factors are less influential on the R pattern identified through drawings than those through surveys, and more influential on the M pattern identified by the former than those by the latter.

4.4 Establishing land-use patterns

Being limited by the availability of PIF data included in questionnaire surveys, the SPAs establish land-use patterns using 18 PRs identified from the BCA detailed plan. The scenario information for region A is shown in table 5 and figure 8. In figure 8 scenario 1 was established using the PRs identified from the planned parcels distributed over the entire BCA, while scenarios 2–18 represent the results using the parcel samples extracted from region 2–18, respectively. Among the 18 scenarios, the largest numbers of R, C, and M parcels are 184 in Scenario 14, 187 in scenario 4, and 11 in scenario 1, respectively, and the smallest are 129 in scenario 4, 116 in scenario 1, and 4 in scenarios 4, 12, and 17, respectively. The average numbers of R, C, and M parcels are 153, 156, and 7, respectively. For spatial distributions of the 18 scenarios, shown in figure 8, R type is mainly allocated in central and eastern parts of region A and several parcels located in southwestern part, C type is mainly allocated in southern part and on two sides of a northern road, while M type is dispersed in region A.

Table 5. Results of established land-use patterns in region A (336 parcels in total).

Scenario	Number of parcels			
	R (residential)	C (commercial)	M (industrial)	O (other)
1	163	116	11	46
2	144	166	10	16
3	142	173	6	15
4	129	187	4	16
5	142	169	9	16
6	132	180	9	15
7	136	177	8	15
8	167	149	5	15
9	160	152	8	16
10	142	168	10	16
11	157	156	8	15
12	170	147	4	15
13	136	178	8	14
14	184	129	8	15
15	157	157	6	16
16	174	131	10	21
17	170	146	4	16
18	142	131	5	58

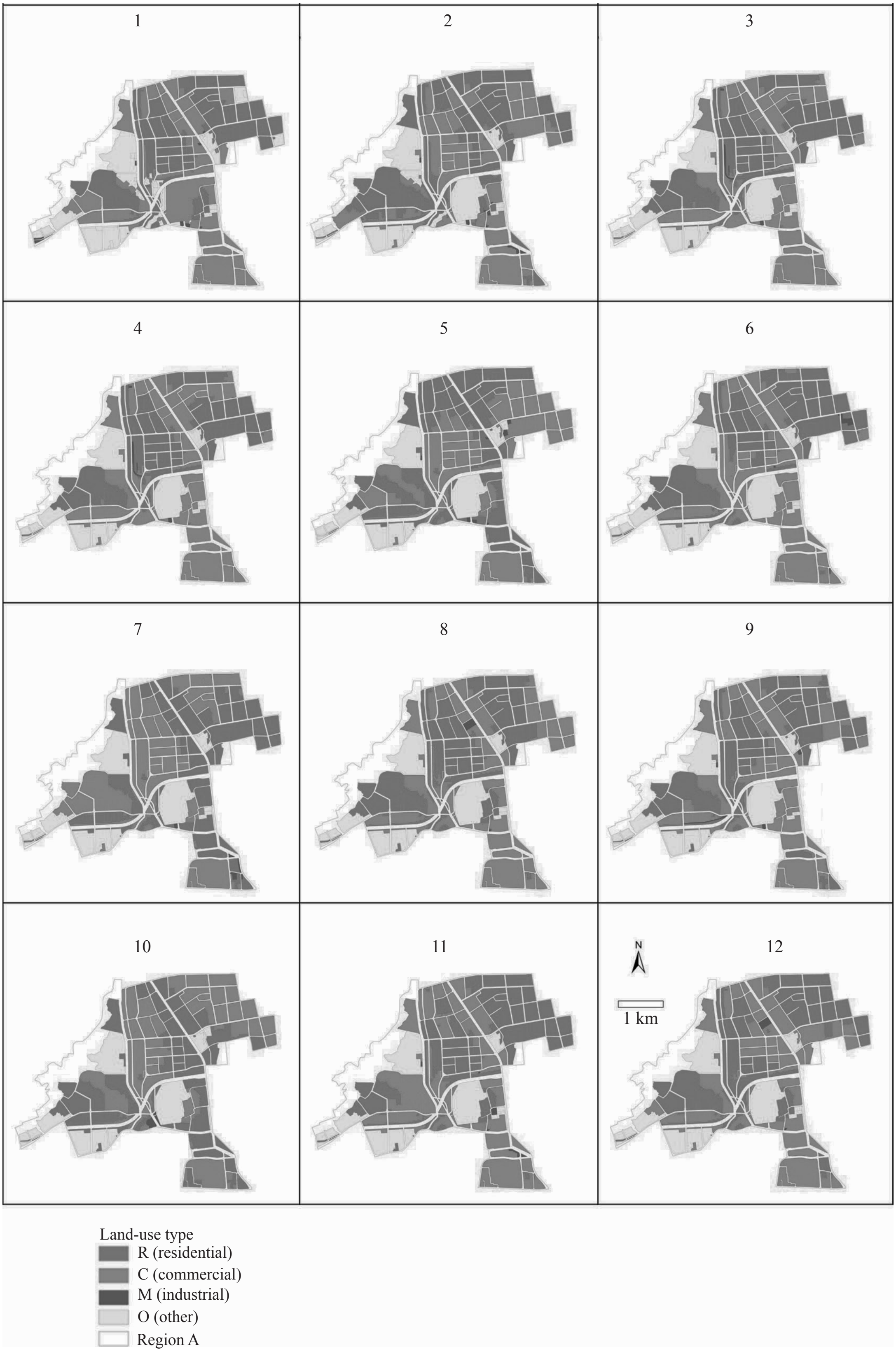

Figure 8. [In color online.] Established land-use patterns by 18 spatial planner agents in region A.

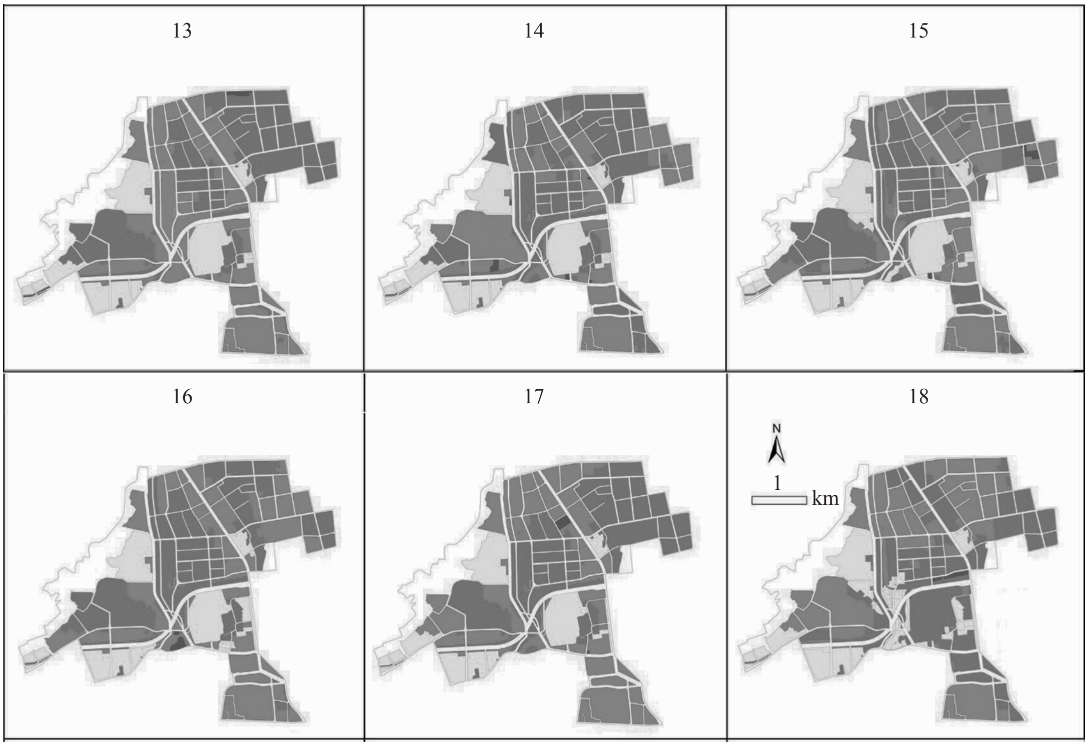

Figure 8 (continued).

4.5 Establishing the final land-use pattern

At first, the probability of P_{nk} is calculated based on the frequencies of R, C, and M types for parcel n in the 18 established scenarios. Figures 9(a), (b), and (c) show the probabilities of R, C, and M, respectively. It is convenient to discern from the figure the parcels which have higher or lower probabilities of being distributed as a certain land-use type. Then, the CPA establishes the final land-use pattern using steps 2–7 of the flow given in subsection 2.3.3. The final scenario is shown in figure 9(d). The scenario reflects the requirements and preferences of the 18 SPAs equally, and also the demands and inclinations of the GA. Therefore, it can be regarded as a relatively reasonable land-use pattern. For the RA's opinions, the CPA will determine the final land-use pattern after negotiating with the RA.

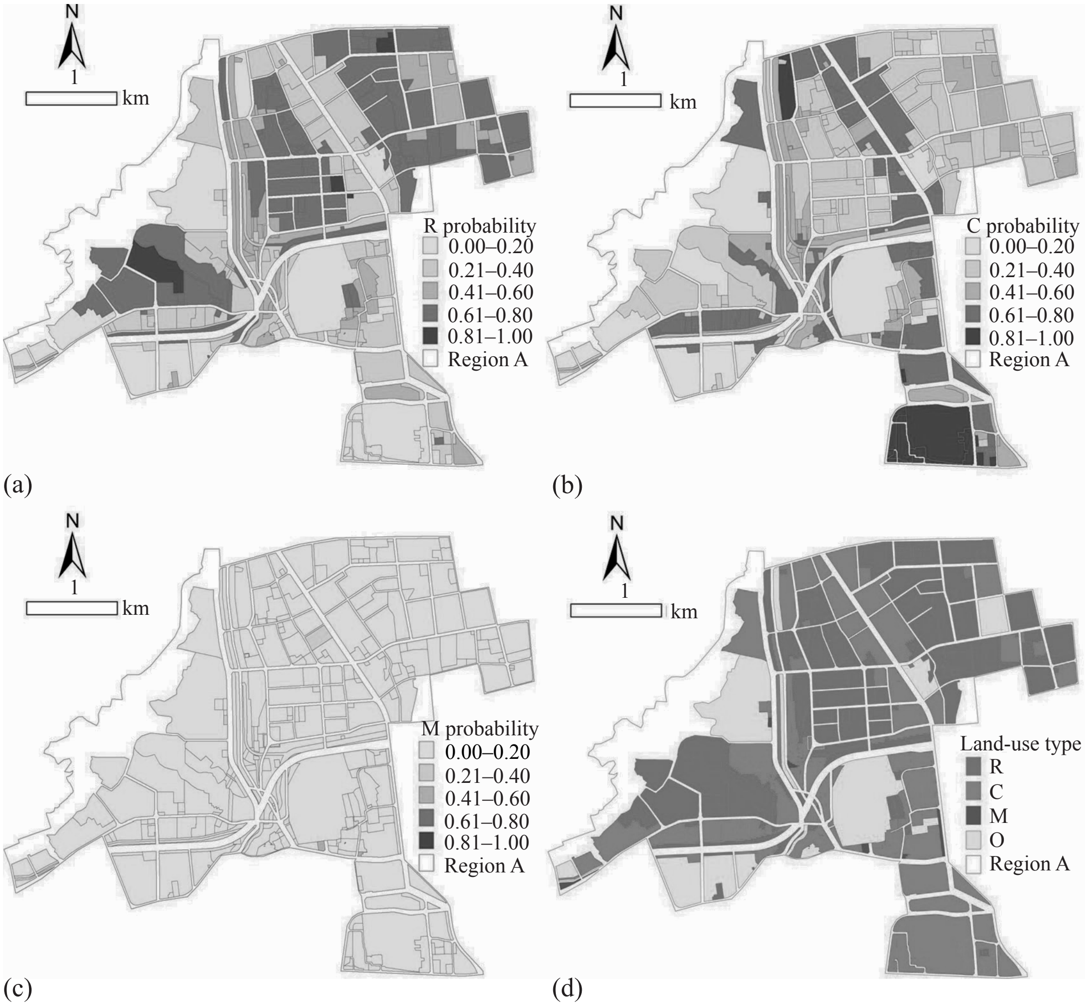

Figure 9. [In color online.] The probability distributions of (a) R (residential), (b) C (commercial), and M (industrial); (d) the final land-use pattern established by the chief planner agent.

5 Conclusion and discussion

In this paper we introduced two aspects of our work. First, the PA framework was proposed for supporting LUPSA. PRs can be identified by several methods, such as the use of existing plan drawings, questionnaire surveys, real models, and virtual reality tests. Combined with identified PRs, comprehensive constraints by the GA, and special plans formulated by NPAs, the land-use pattern can be established by the SPA. The final land-use pattern can be established by the CPA, on the basis of established scenarios formulated by several SPAs. Following this, the CPA negotiates with the RA to determine the final scenario. Second, the framework of PAs was applied in a virtual space and in Beijing. The virtual space test shows the feasibility of the PA framework for supporting LUPSA. For the Beijing experiment, PR identification was implemented through plan drawings and by questionnaire surveys completed by planning professionals, and PRs based on both methods were compared. We established 18 scenarios using PRs mined from plan drawings by 18 SPAs, and finally the final planned pattern was accomplished by the CPA. Results show that the proposed PA framework is suitable for LUPSA in a real situation.

This framework of PAs emphasizes the uniqueness of planners and the influence of their opinions, as well as the importance of other actors. It also considers the negotiation between participating agents, thus providing a useful framework that reasonably reflects the requirements and preferences of different agents in supporting LUPSA. Our framework uses the parcel as the analysis unit, and establishes the entire city's land-use pattern scenario in a bottom-up manner. Considering the rapid urbanization in China, the requirement for urban planning is much more stringent than before, so our proposal has a strong potential in practical applications. The framework of PAs was proposed in the context of urban planning in China, but when applied to other countries some variations may exist (eg, who will participate, at which stage they participate, and what level of the participation). A developer agent may also be a main participant in some countries and the RA may participate before the detailed establishment of land-use patterns and may play a more important role in countries where public participation is emphasized more. Therefore, some corresponding adaptations are needed when translating our framework, which is proposed for China, to other contexts.

For applicability to real-world situations, the PA framework could be improved in future in the following ways. First, communication and coordination between the SPA and NPAs should be considered. This could be achieved by referring to the form scenario analysis approach proposed by Long et al (2010). Second, although PRs can be identified quantitatively by various methods, it remains difficult to reflect PR elements comprehensively, especially given the planner's subjective uncertainties. We aim to improve the methods for identifying PRs, for example, by considering PIFs more comprehensively and improving their data availability, identifying PRs using real models or virtual reality tests, and comparing the effects of different methods. Third, we would take public participation into account by introducing the RA into our research; this would facilitate evaluation of land-use pattern scenarios based on the principle of resident utility maximization. Finally, we intend to extend applications of the framework, for example, by supporting the formulation of floor-area ratios in addition to the land-use types used here.

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